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METALLURGY

INSTRUCTION PAPER

REVISED BY

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1905

AMERICAN SCHOOL OF CORRESPONDENCE

AT

ARMOUR INSTITUTE OF TECHNOLOGY

CHICAGO

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METALLURGY.

IRON.

For centuries iron has been the most useful metal known to man. In the earliest periods of history, stone implements were used; later bronze, an alloy of copper and tin, replaced stone. After a time men found a way to extract iron from its ores, and the Iron Age began. As nothing has yet been discovered, or invented, to take the place of iron in the arts, the Iron Age has continued until the present day. The process of separating, or extracting iron from its ores; of smelting and refining it; and of making it into its most useful form, steel, is called the metallurgy of iron. From small beginnings, this art has gradually increased to its present importance.

ORES.

Iron is never found pure; it is always compounded with other elements or minerals. These compounds, called ores of iron, occur in enormous quantities, and are widely distributed in the earth. The value of an ore depends upon its richness, its locality, the ease with which it can be smelted, and its freedom from phosphorus and sulphur. The principal ores are:

Magnetite, magnetic iron ore (Fe_3O_4). It is black, heavy and crystalline. The finest quality is found in Sweden, and sometimes contains as high as 72 per cent metallic iron. This ore usually contains from 40 per cent to 60 per cent metallic iron. A high temperature is required to reduce it.

Hematite, oxide of iron (Fe_2O_3). A red ore containing about 70 per cent of iron when pure; it is sometimes called "Hard Ore." About 82 per cent of all the ore now mined in the United States is red hematite.

Limonite, or brown hematite ($2\text{Fe}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$). Contains water which can be expelled by heat, leaving the ore of a reddish

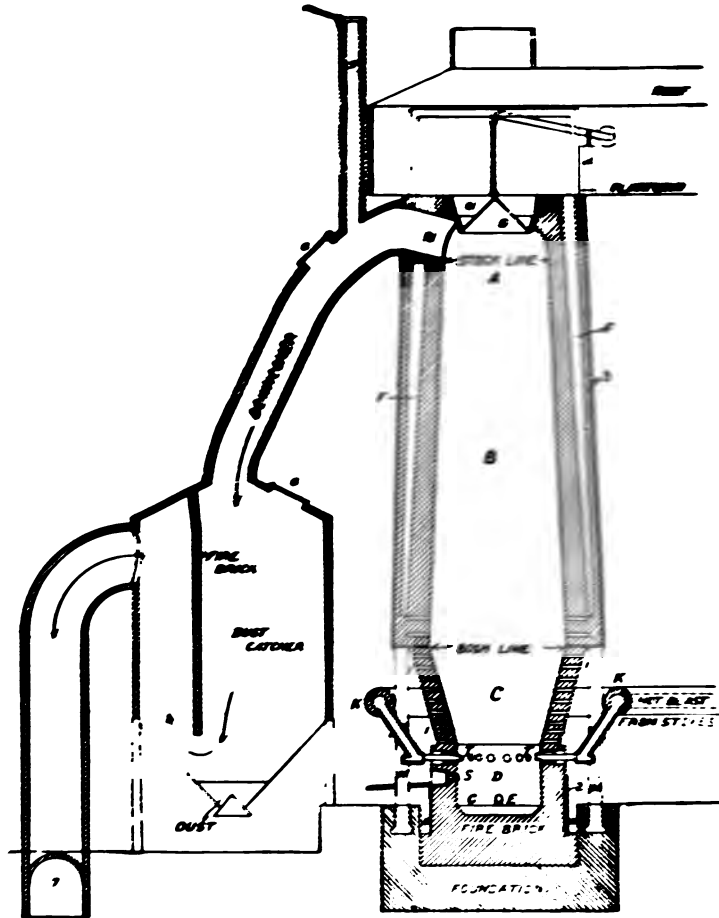


Fig. 1.

1. BRONZE COOLING PLATES.
2. CRUCIBLE JACKET.
3. WHEEL.
4. BELL CYLINDER.

5. BLEEDER.
6. EXPLOSION DOORS.
7. PLUE LEADING TO STOVES AND BOILERS.
8. DITCH FOR WATER.

HEIGHT, 90 FEET.
 DIAMETER AT BOSH LINE, 20 FEET.
 DIAMETER AT CRUCIBLE, 14 FEET.

DIAMETER AT STOCK LINE, 15 FEET.
 HEIGHT OF TUYERE CENTER, 5 FEET.
 CAPACITY, 400 TONS PER DAY.

color. When pure this ore contains about 60 per cent of iron, and from 8 per cent to 20 per cent of water.

Siderite, or carbonate (FeCO_3) or (FeOCO_2). This is an important ore in Europe, although containing only about 48 per cent iron. It requires careful preliminary roasting before smelting.

Iron ores are never found pure; they contain varying quantities of silica, alumina, calcium, manganese, sulphur and phosphorus.

MINERALS.

The principal minerals used in iron smelting are:

Iron Pyrites or fool's gold (FeS_2). It occurs in cubic crystals and bright shining scales. This mineral is used as a source of sulphur in the manufacture of sulphuric acid. In some cases it is smelted for iron after its sulphur has been used.

Franklinite, or oxides of iron, manganese and zinc (FeO MnO ZnO) ($\text{Fe}_2\text{O}_3\text{Mn}_2\text{O}_3$). It contains about 46 per cent of iron. It is used in the manufacture of zinc white and spiegel-eisen. "Spiegel," is a coarsely crystalline variety of cast iron, with large crystal planes having bright reflections. It usually contains about five per cent of combined carbon and 10 per cent to 20 per cent of manganese.

Limestone, Chalk or *Oyster Shells*,—carbonate of calcium (CaCO_3). Used as a flux.

Dolomite, carbonate of calcium and magnesium [$(\text{Ca Mg})\text{CO}_3$], sometimes substituted for limestone.

PREPARATION OF ORES.

Usually the ore is broken into small pieces and then reduced to metallic iron in the blast furnace. Sometimes it is broken into small pieces, piled up, and exposed to the air and rain. By this means dirt, sand and soft rock are washed out. In this country iron ore is seldom roasted, but when necessary it is roasted in kilns, thus driving out the sulphur.

THE BLAST FURNACE.

The blast furnace is located in a place where materials may be economically assembled, product cheaply transported to market, and a good water supply is available.

The blast furnace is a circular brick or stone structure, lined with fire brick and encased in sheet iron. The general arrangement is shown in Fig. 1. The throat at A is about 15 feet in diameter; the main portion B, called the shaft, is nearly cylindrical and about 60 feet high and 20 feet in diameter. The lower portion C, which is shaped like an inverted frustum of a cone, is called the boshes and is about 20 feet high and 14 feet in diameter in the smallest part. Below the boshes a cylindrical portion D, called the hearth, extends about 10 feet and is lined with fire brick. This total height is about 90 feet, but some are over 100 feet high. The tuyeres T, 6 to 16 in number, are pipes through which hot blasts of air are blown and are built into the brick-work about 6 feet above the bottom of the hearth. The tuyeres are made as simple as possible and constructed so that they may be easily taken out and replaced. The bustle pipe K, supplies air to the tuyeres. The part of the hearth G, below the tuyeres is called the crucible, which being subjected to intense heat, is often cooled by water flowing through a series of open gutters around it. The boshes are kept cool by water circulating through a series of cooling rings, cast in bronze blocks and set in the brick or masonry walls.

There are two openings in the crucible wall; the upper, called the cinder notch for the removal of slag or "cinder," and the lower for the molten cast iron. The upper or "slag eye" S, is stopped up by an iron plug on a long handle; but the lower or "tap hole" E must be plugged with clay. Balls of clay are rammed in and soon baked as hard as stone by the heat. For large furnaces a "gun" is used to force the clay balls into the hole. This clay is two or three feet in thickness and when the iron is ready to flow out it is drilled. The work of drilling through this clay is considerable, and in modern furnaces is done by a steam tapping hole drill.

Just above the throat is the bell O and hopper H (Fig. 1). The materials are placed in the hopper and dumped into the throat of the furnace, by lowering the bell. The bell is raised and lowered by levers and counter-weights, operated by steam or compressed air.

The gases leave the top of the furnace just below the bell at

N; they pass through a dust catcher and then go to the stoves and boilers to be used as fuel. The stoves are used to heat the air for the tuyeres, and the boilers furnish steam for the blowing engines and hoisting engines.

The columns M support the weight of the furnace. The whole rests on the masonry foundation. The space F, called the expansion space, allows for the expansion of the inner wall; it is sometimes packed with granulated slag.

MATERIALS.

The materials used in the blast furnace are:

Ores, already briefly described.

Fluxes. Flux is the substance added to combine with the earthy impurities and make a fusible slag which floats on the molten iron. The impurities which would soon clog up the furnace, are thus removed. Limestone and Dolomite are the usual fluxes. Oyster shells are used in Maryland on account of cheapness.

Fuels. The fuels used are coke, which is made in beehive ovens from soft coal; charcoal, which is wood charred in heaps or kilns; anthracite coal, and very rarely bituminous coal.

The fuel depends largely upon the locality. Charcoal is a good blast furnace fuel on account of its porosity, slight ash, and freedom from sulphur. Coke is the best fuel because it is strong enough to resist being crushed by the great weight of materials and because it burns rapidly thus giving a large output. Anthracite coal breaks up very fine and burns to CO slowly. A good mixture is $\frac{1}{4}$ coke and $\frac{3}{4}$ anthracite coal. Bituminous coal is rarely used as it cakes and absorbs heat.

OPERATION OR RUNNING.

Blowing in. To start the blast furnace it is first thoroughly dried and then filled with cord wood to about half-way up the boshes. Upon this is placed a blank charge of coke, and then successive layers of fuel, flux and ore, with gradually increasing amounts of ore, until the regular charge is reached. The wood is then lighted and the hot blast of air turned on. At first this blast is under slight pressure. When coke is used the iron begins to flow in about 15 to 20 hours after lighting.

The ore, fuel and flux are brought to the scales in barrows called buggies. They are then weighed and wheeled to the elevator, and a certain number of barrows of each dumped into the hopper. In many large furnaces self-dumping cars are run to the top on an inclined railway, and the charging is entirely automatic. The fuel charge is usually dropped in by itself, followed by the ore and flux. The level of stock in the furnace is kept constant by regulating the charges. The temperature of the blast is kept as nearly constant as possible, being regulated by the admission of cold air. Cold water is kept running through the cooling rings around the bosh walls. Slag is either drawn off at intervals or continuously, and the molten iron which collects in the crucible, is drawn off every four to six hours by drilling the tap hole. It runs into channels formed in sand; the main channel is called the sow, and the smaller ones branching from it, the pigs. When solid the pigs are broken apart and stacked ready for transportation. The latest development in pig casting is an apparatus consisting of an endless iron mould which revolves and receives the charge and discharges the cooled pigs on the cars.

The furnace is run continuously day and night until it is necessary to shut down for repairs. Sometimes furnaces are run continuously for three to five years.

A good-sized blast furnace using coke as a fuel, will produce 300 tons of pig iron every twenty-four hours, and some of the largest can turn out 600 tons.

BANKING THE FURNACE.

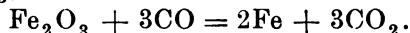
It is sometimes necessary to shut down the furnace, because of a falling market, a flood, or a strike. If it is to be banked at a moment's notice, the first thing to do is to tap out the metal, shut off the blast and the water jackets; then close the furnace so that there will be no draft through the shaft. The tuyeres are blanked by ramming in clay balls. In this case the blast should be resumed in two or three weeks. If there is time to plan the shutting down, a large charge of fuel is dumped in and successive charges containing an increasing proportion of ore. The blast is shut off when the fuel reaches the tuyeres; the bell sealed and the cooling water decreased. The blast need not be resumed in this case for four or five months.

To blow out for repairs, stop the ore charges, and continue to charge fuel with a small amount of flux until the flow of metal ceases.

THE CHEMISTRY OF THE FURNACE.

In the blast furnace the oxides of iron give up their oxygen and become metallic iron. The most important substance for effecting this change is carbon monoxide CO. As we learned in Chemistry, CO gas has an affinity for oxygen, tending to form CO₂.

At the tuyeres the carbon burns to CO. Near the top of the furnace, at a temperature of 400° to 600° F, this CO reduces the iron ore (Fe₂O₃) to metallic iron, thus



The iron is not melted here, but is in a pasty condition. The charge gradually descends, getting hotter and hotter. At the boshes it is at a bright red heat, and in the lower part the iron begins to melt, and the lime, silica and other earthy materials fuse and form slag. At this point part of the silicon, manganese, sulphur and phosphorus are reduced, and together with a little carbon, combine with the iron. In the crucible all is melted and the temperature is above 2200° F.

SLAG.

The earthy materials, silica, alumina, and sulphur of the ore and fuel, combine with the flux, and form the slag. A large part of the sulphur is then eliminated from the ore; but none of the phosphorus. The quality of the iron depends largely on the composition of the slag. If a high lime slag is used in order to reduce the sulphur and silicon in the pig iron, there is danger that the slag may not run well, in which case more alumina is used. A good slag has approximately the following constituents: 52 per cent CaO + MgO, 16 per cent Al₂O₃ and 32 per cent SiO₂.

STOVES.

In the first blast furnaces cold air was used for the blast. Stoves were introduced to effect a saving of fuel and to increase the out-put. The waste gases from the blast furnace contain about 25 per cent of carbon monoxide, CO, and 1 per cent of

hydrogen, H. These gases are burned with air in brick stoves and the fire brick flues are heated to redness. Then the cold air blast is run through and is heated to above 1000°F.

Four stoves are generally used in a set, three being heated while the fourth is giving out heat to the blast. The fuel consumption with a hot blast is about one-half that with a cold blast.

CAST IRON.

The iron produced by a blast furnace, known as cast iron or pig iron, is impure. It contains carbon, phosphorus, sulphur, silicon, manganese, and traces of other elements.

Cast iron is brittle, fusible and cannot be welded. It melts at a temperature of 2100°F. to 2300°F. Gray iron is more fluid when melted, and not as brittle as white iron.

Cast iron is suitable for castings because it expands at the moment of solidifying; this expansion is due to the change in the position of the crystals and results in a sharp impression of the mould. The casting is smaller than its pattern because the shrinkage in cooling from a red hot solid is greater than the expansion at the moment of solidification. If iron moulds are used, the surface of the casting becomes chilled, which causes a harder surface.

The Tensile Strength of cast iron is 13,000 — 29,000 pounds per square inch; Compressive Strength 82,000 — 145,000 pounds per square inch; Modulus of Elasticity 14,000,000 to 22,000,000.

Pig Iron is sometimes graded according to its fracture. This method is satisfactory if the irons are made from uniform ores and mixture of fuels; but is unreliable if the irons are produced in different sections of the country, or from different ores. Grading by chemical analysis is better. There are five standard grades according to hardness.

No. 1. Gray. Fracture rough. It is dark, open grain and the softest grade. Used exclusively in foundry work. Tensile Strength low. Elastic Limit low. Turns soft and tough.

No. 2. Gray. Mixed grain. Harder than No. 1. Fracture less rough, with higher Tensile Strength and Elastic Limit than No. 1. Used in foundry. Turns harder, less tough and more brittle than No. 1.

No. 3. Gray. Close grain. Used in foundry and rolling mill. Turns harder and less tough than No. 2.

No. 4. Mottled. Dotted with small black dots of graphite. Little

grain. Used in rolling mill. Lower Tensile Strength and Elastic Limit than No. 3.

No. 5. White, no grain, smooth fracture. Used in the Bessemer process and in the rolling mill. Tensile Strength and Elastic Limit lower than No. 4. Too hard to turn and very brittle.

The following table gives average analyses of the various grades of cast iron, the amounts being given as per cents:

Grade Number.	Iron.	Graphitic Carbon.	Combined Carbon.	Silicon.	Phosphorus.	Sulphur.	Manganese.
1	92.37	3.52	.13	2.44	1.25	.02	.28
2	92.31	2.99	.37	2.52	1.08	.02	.72
3	94.66	2.50	1.52	.72	.26	Trace	.34
4	94.48	2.02	1.98	.56	.19	.08	.67
5	94.68	—	3.83	.41	.04	.02	.98

INFLUENCE OF CARBON, SILICON, PHOSPHORUS, SULPHUR AND MANGANESE.

Carbon. The state of the carbon in the pig iron is a most important factor in the quality. If the carbon is combined with the iron in the form of an alloy, a hard, brittle, white iron is produced. If it is present mainly as graphite distributed as small crystals throughout the entire mass, the iron is soft and gray in color, but not as strong as white iron. Gray iron expands more on solidifying and contracts less in cooling than white iron.

Silicon. The amount of silicon and the rate of cooling determine the proportion of graphitic to combined carbon in the casting. Increasing the silicon in cast iron increases the proportion of graphitic carbon, thus making the iron softer. A large quantity of silicon renders the iron stiff and weak.

Phosphorus. Phosphorus in general weakens cast iron, but it is not harmful if less than 1 per cent is present. In some cases phosphorus is beneficial, as it decreases shrinkage and increases fluidity. For small, thin castings, iron may contain a little over 1 per cent phosphorus.

Sulphur. Sulphur makes castings hard and unsound. It

also prevents the iron from flowing well. The amount of sulphur should not be over .5 per cent for sharp castings.

Manganese. Manganese in cast iron increases hardness and shrinkage and makes it more brittle. Manganese makes the iron capable of holding more carbon. Sometimes the amount of carbon is as high as 5 per cent, as in Spiegel.

Manganese with some chill is used in the foundry to produce hardness of surface. The magnetism of iron is decreased by manganese ; if 25 per cent is present all magnetism is lost.

CASTINGS.

In order to get a good casting, an iron having the following requisites should be used :

Shows gray fracture.
Is easily worked by tools.
Fills the mould to the thinnest parts.
Chills with a smooth surface.
Free from blow-holes.
Has moderate strength.
Little shrinkage.

An iron with the following constituents fills these conditions:

Carbon,	3½ per cent.
Silicon,	1½ per cent to 2 per cent.
Phosphorus,	not over .7 per cent.
Sulphur,	only a trace.
Manganese,	.35 per cent to .70 per cent.

For large castings lower the silicon. For increase in strength lower the carbon, silicon and avoid phosphorus. For resistance to chemical action make the manganese as high as brittleness will allow.

Silver-gray and ferro-silicon irons are used to increase silicon. Spiegel and ferro-manganese are used to increase manganese. Both wrought iron and steel scrap are used to reduce carbon.

MALLEABLE CAST IRON.

Malleable cast iron is a crude form of wrought iron obtained by decarbonization. The castings are made in the ordinary way from low silicon iron with little phosphorus and sulphur ; they are embedded in oxide of iron or peroxide of manganese and heated to a red heat until most of the carbon is removed from the

surface. The time necessary for this operation is three to fourteen days, depending upon the size of the casting.

An analysis for good malleable iron is:

Si	.75 — 1.00 per cent.	P	.20 per cent.
S	below .05 per cent.	Mn	.40 to .75 per cent.

This will be a No. 3 iron.

In making malleable castings, sharp angles and abrupt changes from heavy to light sections should be avoided. Several thin ribs in place of one thick rib should be used. As much surface as possible should be exposed, as the strength lies in the skin.

WROUGHT IRON.

Removing most of the carbon, silicon, phosphorus and manganese from pig iron makes it tough, malleable, harder to melt and capable of being welded. This iron is known as wrought iron, and is obtained by a process called puddling. The operation of

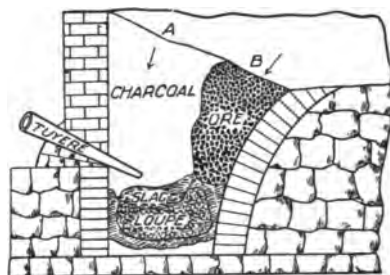


Fig. 2.

making wrought iron from the ore is called a Direct Process. On account of its simplicity it was the first used.

The Direct Processes are carried on at a low temperature; the production is small and variable, and about 20 per cent of the iron in the ore is lost. One of the oldest methods of making

wrought iron directly from the ore is the Catalan Process. Ore of egg size is charged at B, Fig. 2, and charcoal at A. As the smelting progresses, charcoal and moist fine ore are charged at A. As the ore becomes reduced it works towards the tuyere; when it is all reduced it is taken out in a large lump called the "loupe" and worked under a hammer.

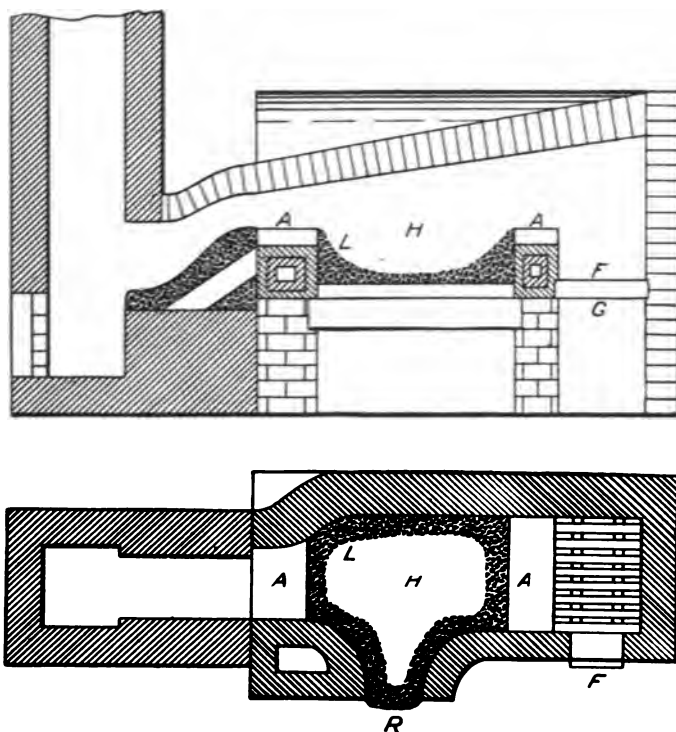
There are other processes, but they are unimportant and most all have been abandoned.

THE PUDDLING PROCESS.

The refining of pig iron by puddling converts it into wrought

iron. This process is carried on in a reverberatory furnace. Fig. 3 shows sectional view of the plan and elevation.

The furnace has a low-arched roof and oval hearth H. The flame from the fire passes over the charge of iron, which is melted by the intense heat. The pig iron used in this process is gray and unrefined and has more silicon than white iron. The fettling or lining L of the hearth is made of good magnetite or hematite. The fettling is repaired after every heat.



A. — BRIDGES.
F. — FIRE-DOOR.

Fig. 3.

G. — GRATE.
R. — RABBING-DOOR.

Carbon, silicon, manganese, phosphorus and sulphur unite with oxygen from the hot blast and the iron ore lining, thus reducing the molten metal to wrought iron. In order that the whole of the metal may come in contact with the fettling it is stirred constantly by rods called "rabblers." It takes about thirty minutes to melt down, and then carbon begins to be oxidized to

CO gas, which makes a violent boiling for about 15 minutes. The silicon, manganese, etc., oxidize and form a slag. When all the carbon is boiled out, bright points appear and the iron becomes pasty. The iron is gathered into balls and then worked under the hammer and rolls to expel the slag. It is afterward reheated and rolled between grooved rollers, which causes the particles to become close together. If the bar is rolled once it is called muck bar; if cut up, heated and rolled again, merchant bar; the best bar iron is rolled a third time.

The Puddling Process and the manufacture of wrought iron is gradually giving way to mild steels; but because of the small amount of slag it contains between the fibres, which acts as a flux, wrought iron welds much easier than steel and is preferred by blacksmiths.

The Puddling Process is expensive on account of the large amount of fuel used in the production of metal. About one ton of fuel is necessary to produce one ton of muck bar. For this reason and on account of the expense of the mechanical work of puddling, many efforts have been made to produce a cheaper and more simple process.

Boilers have been mounted over the furnace to utilize the waste gases as fuel, but on account of the fluctuating heat of the furnaces they have not been entirely successful. Water-tube boilers mounted in this way have been the most satisfactory.

There are several contrivances to save fuel and labor, but as the mechanism is likely to get out of order, they are not always reliable. For saving of labor, the Dank's Puddling Furnace, Fig. 4, is the most efficient and satisfactory of the mechanical puddlers. It is shaped like a short barrel, lying on its side. It is supported by friction rollers, two at each end, and driven by a large gear G around its middle. In this furnace the revolving of the hearth takes the place of puddling or stirring by hand.

Iron ore worked in layers at low heat forms the fettling. It is fed with molten iron from a furnace by means of a ladle. In some places this furnace is used for ordinary puddling, and in others for making wrought iron for the Open-hearth and Siemens Processes for making steel.

Wrought iron contains from .5 per cent carbon to only a

trace; as carbon decreases, malleability increases, and the melting point rises. The melting point of good wrought iron is about 3000°F.

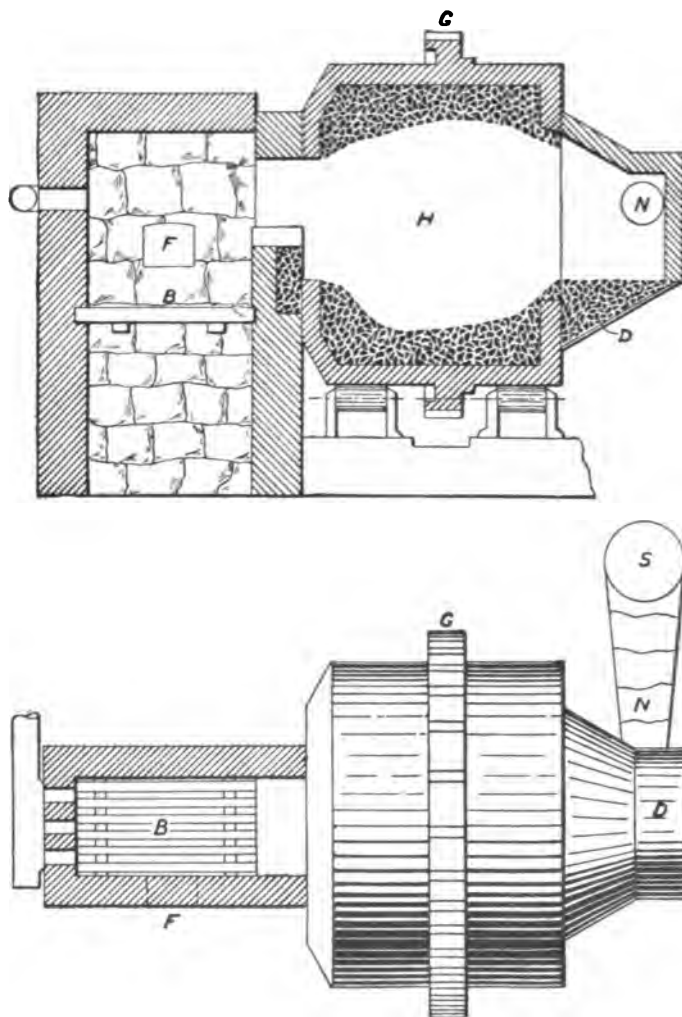


Fig. 4.

B—GRATE.
F—FIRE-DOOR.
H—HEARTH.

D—MOVABLE FLUE-PIECE.
N—FLUE TO STACK.
S—STACK.

Wrought iron contains about 2 per cent of slag distributed among the fibres. It is always present because the iron is finished

in a pasty condition and the slag is never completely removed by the subsequent squeezing and rolling.

The fracture of wrought iron is coarsely fibrous, sometimes showing a few bright granular spots. The best iron is granular when broken suddenly.

The reduction of area of bars by rolling influences the strength and elastic limit. In general, the greater the reduction the higher the strength and elastic limit. Underheated bars have an unduly high tenacity and elastic limit.

The absolute strength of wrought iron is not materially altered by cold. The extensibility, or ductility, is not less in severe cold than at ordinary temperature. The modulus of elasticity rises as the temperature falls.

WELDING.

The process of welding consists of heating two pieces of iron to a high temperature, laying them together and hammering. Borax is sometimes sprinkled on the surfaces to be united, in order to keep them bright. This is accomplished by the union of borax with the oxide forming a fusible borate. In order that the form of the piece after welding may not be spoiled by hammering, the two ends to be joined are upset and scarfed. The upsetting makes the ends larger, so that they may be hammered without making the joint too small, and the scarfing roughens the ends, making the pieces join more easily.

STEEL.

CEMENTATION PROCESS.

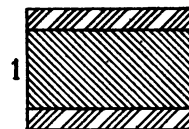
Cement or blister steel is made from wrought iron by this simple process. The purest, soft wrought iron is heated to redness while completely covered with charcoal. The temperature is kept constant for over a week. The iron takes up some of the carbon from the charcoal and is converted into steel. It is called blister steel on account of its appearance, the surface being covered with small scales or blisters. These bars of blister steel are cut, heated and rolled together, forming shear steel. If the process is repeated, the product is called double shear steel.

Blister steel that has been cut up, melted in a black-lead pot and cast in an ingot, is called cast or crucible steel.

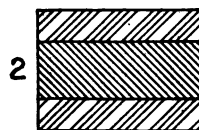
The metal used in Sheffield, England, is wrought iron made from Swedish pig iron. Hammered wrought iron bars are laid in firestone pots in layers, surrounded with charcoal. At one end is placed a test bar, so arranged that it may be drawn out, examined, and returned. The temperature is gradually increased for 7 days to about 1150° F., and then the furnace is kept at this temperature for 7 or 8 days more. It takes 7 days for it to cool down.

When the bars are taken from the charcoal, the outside layers are converted into steel, leaving the center wrought iron. The use for which this steel is intended determines the amount of conversion; the various kinds are classified as follows:

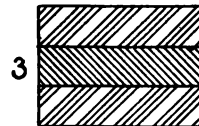
(1) Spring heat, .5 per cent C.
Large iron center.



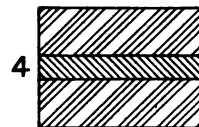
(2) Country heat, .63 per cent C.
Smaller iron center.



(3) Single shear heat, .75 per cent C.
Equal iron and steel.



(4) Double shear heat, 1 per cent C.
Mostly steel.

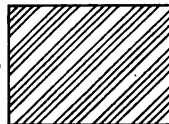


(5) Steel through heat, 1.25 per cent C.
All steel.

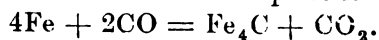


(6) Melting heat, 1.5 per cent C.
All steel.

5
AND
6



The reaction which takes place is



CRUCIBLE PROCESS.

The materials are bar iron with charcoal, puddled bar or blister steel and charcoal. The crucibles are made of clay or graphite, with a capacity of 50 to 85 pounds. The charge is put into the crucible, and after melting is allowed to stand for a time, called the killing period, and then poured into moulds.

In American practice, graphite crucibles are used, which are made from a mixture of fire-clay and sand, and about 50 per cent graphite. This mixture is ground, allowed to stand for a few days, and is then moulded by being pressed into a wooden mould. When dry, it is baked in a kiln. These crucibles can be used about five times, if the successive charges are gradually diminished in amount.

The crucible is charged cold. The pieces of iron are surrounded with charcoal, with a little manganese, and sometimes a little salt or ferrocyanide of potassium mixed with it. This crucible, after being covered, is placed standing on the coal in a hot furnace. After three hours, during which the contents are melted, the cover is lifted, and the melter examines the charge to determine the length of the "killing" period. During this period, which is about 45 minutes, the metal is becoming tranquil and is taking silicon from the sand in the walls of the crucible. The silicon prevents blow-holes. At the right time and temperature the crucible is lifted out and the slag skimmed off. The metal is now ready for casting, or "teeming." This is done by pouring the metal into split moulds.

The ingots are graded and hammered into bars for different uses. Crucible steel furnishes the finest grades for cutlery and machine tools; it is superior to Bessemer and Open-hearth steel, because pure materials are used and the process is carried on in a closed vessel, thus protecting the metal from sulphur gases from the fuel.

It has low phosphorus, low sulphur, no iron oxide, less gases, high carbon and high silicon.

Crucible steels are graded as follows :

Razor. $1\frac{1}{2}$ per cent C. Easily burned, very hard temper, welded with difficulty.

Saw-file. $1\frac{3}{4}$ per cent C. Not easily burned, hard temper.

Tool. $1\frac{1}{4}$ per cent C. Not easily burned, hard temper, welded with difficulty.

Spindle. $1\frac{1}{2}$ per cent C. Not easily burned, hard temper, welded with difficulty.

Chisel. 1 per cent C. Not easily burned, fair temper.

Set. $\frac{7}{8}$ per cent C. Difficult to burn, little temper, easy to weld.

Die. $\frac{3}{4}$ per cent C. Difficult to burn, little temper, easy to weld.

THE BESSEMER PROCESS.

Bessemer, by his experiments, found that the temperature of molten metal was raised by blowing a current of air through it.

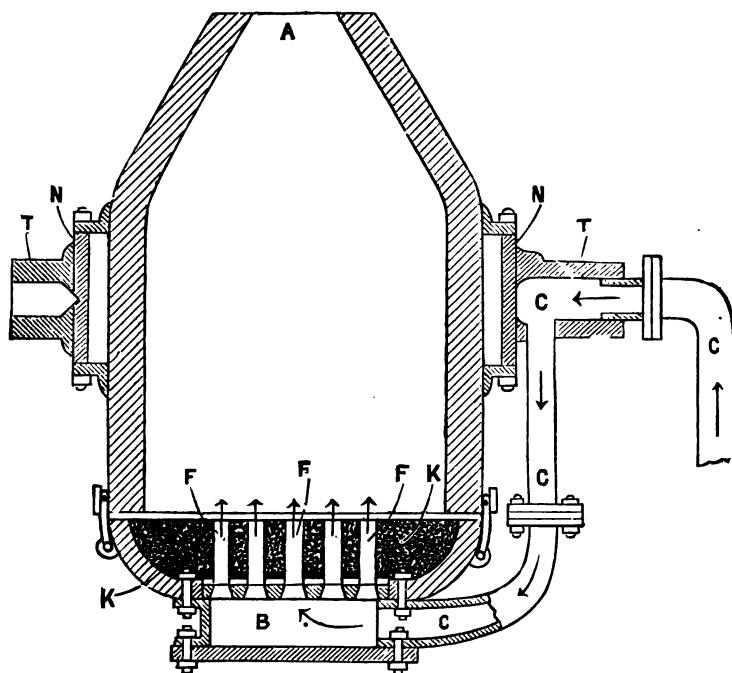


Fig. 5.

He tried to make wrought iron from pig iron, but found that the metal taken from the converter at that point was worthless; by restoring carbon by means of an alloy the product was better than wrought iron.

By this process steel is made from pig iron by burning out the foreign substances and replacing the necessary amounts of carbon, and manganese. These foreign substances—silicon, car-

bon and manganese — are burned out by blowing a blast of cold air through the molten pig. The desired amounts of carbon and manganese are replaced by mixing the proper proportion of spiegel with the molten pig.

The process is carried on, not in a furnace but in a vessel called a converter, in which molten pig is “converted” into steel.

There are several forms of converters. Fig. 5 shows a concentric converter. It is round, with a detachable flat bottom. The outer casing is of sheet iron. It is filled and emptied at the nose A. The current of cold air enters through the pipe C, and passes through the trunnion T. It enters the converter from the wind-box B, passing through the tuyeres F. The tuyeres are of fire brick 24 to 28 inches long, and have 19 holes $\frac{5}{16}$ inch in diameter, or 7 holes $\frac{3}{8}$ inch in diameter. The trunnion rings N are fastened to the converter, which turns on the trunnions T. The bottom is coupled on with clamps.

The pig iron is not melted in the converter, but poured into it in a molten state.

There are two processes of working.

- (1.) The Acid Bessemer.
- (2.) The Basic Bessemer, or Thomas-Gilchrist.

The difference is in the lining of the converter. If this lining is acid (siliceous) no phosphorus or sulphur is burned out of the pig. Only irons with small amounts of these elements can be used in this process. If the lining is of lime or magnesia all the phosphorus and almost all of the sulphur can be burned out. Only a high phosphorus pig can be used in the basic process, as the heat needed to keep the steel liquid, during casting, is obtained from the phosphorus.

The Basic Process is used in Germany with good results.

In both processes the carbon, silicon, manganese, etc., are oxidized, leaving the molten iron in a condition similar to that of wrought iron. The carbon passes away as CO, and the oxides of silicon and manganese with a little iron oxide form a slag. Molten spiegel is added to give it the necessary carbon, and a little manganese to make it malleable. The molten pig is obtained in two ways; by melting the pig in cupolas, called the Cupola Process; and by taking the iron from the blast furnace, called the Direct Process.

THE CUPOLA PROCESS.

Pig iron, from piles which have been sampled and analyzed, is loaded into trucks and wheeled to the cupolas. The composition of this mixture is about as follows :

Silicon	1.75 per cent.
Manganese	.75 per cent.
Sulphur less than	.05 per cent.
Phosphorus less than	.10 per cent.
Copper less than	.10 per cent.

This is weighed, hoisted to the cupola and dumped in. Spiegel is sampled, analyzed and melted down in smaller cupolas. The fires in the cupola are started with wood upon which is placed coke; the charges of pig iron being dumped on the coke. It takes about two hours to melt the first charge. As some silicon burns out in the cupola the percentage is reduced. When the iron goes into the converter there must be from 1 to 2 per cent silicon present, depending on the temperature of the iron.

THE DIRECT PROCESS.

In the ordinary blast furnace, different casts differ too much in silicon and sulphur to allow taking the metal as it flows from the furnaces into the ladle and then to the converter. Therefore, it is first poured into large reservoirs or mixers, in which the casts from the different furnaces are mixed. In Sweden, however, the product from a number of small charcoal furnaces is regular enough for the iron to be used directly. The iron is taken from the mixers as wanted and used as cupola iron. If the iron stands in the mixer a long time some sulphur is eliminated, but no carbon or silicon. To prevent the iron from chilling on top, a jet of oil is sprayed over it. As the temperature of direct iron is greater than that of cupola iron, less silicon is needed.

Blowing. The heated bottom is coupled on and the joint rammed tight from the outside. When the lining is made yellow-hot by means of a fire of wood and coal with a gentle blast, the iron from the cupola or the mixer is poured in and the blast turned on.

The converter is turned up to a vertical position, as shown

in Fig. 6, as it is filled when turned down on its side. The blast rushes up through the bath, and silicon begins to oxidize raising the temperature high enough for the carbon to burn. Carbon burns to CO. The blower judges whether there will be enough heat to keep the steel liquid during the casting, by the appearance of the flame which comes out of the throat of the converter. If he thinks there will not be enough heat, the converter is turned half-way down and the CO burns to CO_2 . Fig. 7 shows the converter turned down until the tuyeres are exposed.

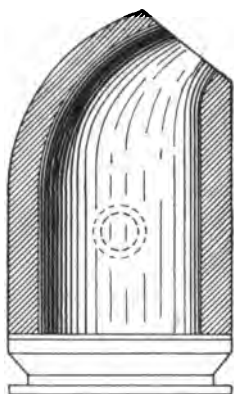


Fig. 6.

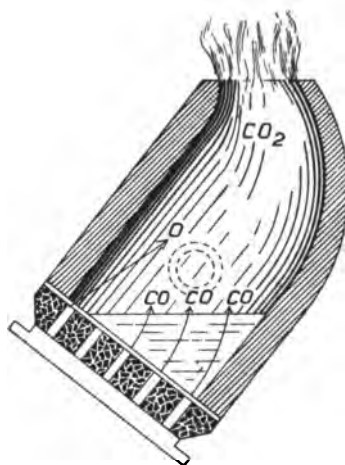
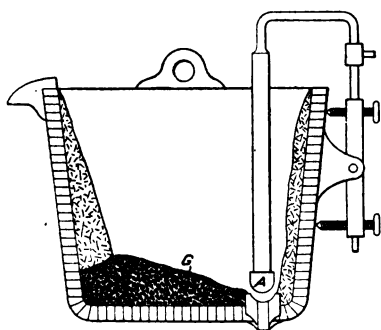


Fig. 7.

In case there is too much silicon for good working, or if the charge is too hot, cold steel scrap is dropped into the nose of the converter from a platform above. The scrap, being free from silicon, reduces the percentage of silicon in the converter. If the steel is made too hot it will not roll well. Sometimes a jet of steam is admitted to the blast pipe to cool down a charge. The carbon is reduced to about .05 per cent after about 12 minutes blowing under a pressure of 30 pounds per square inch. This is shown by a shorter flame. An instant later the flame becomes fringed with brown smoke which is Fe_2O_3 . The converter is now ready for the spiegel. The spiegel contains about 20 per cent manganese and 4.5 per cent carbon. If hard steel is being made, spiegel is used, but if it is to be soft, which requires

some manganese and but little carbon, ferro-manganese is used instead of spiegel. This has 80 per cent manganese and 6.5 per cent carbon. The amount of molten spiegel added is about 10 per cent of the weight of the converter charge, and of ferro-manganese from 1 per cent to .8 per cent. The ferro-manganese is not remelted but shoveled red hot in pieces the size of an egg into the casting ladle. After the steel has been poured out into the ladle most of the slag remains in the converter. It is dumped into a car beneath by tipping the converter bottom up. This loss or waste is from 10 per cent to 12 per cent.

The charge varies from 5 tons in a small converter to 20 tons in a large one, and a new charge is blown every twenty minutes. The bottoms of the converters are examined and any



-Fig. 8.

bad tuyeres are plugged with plumbago mud and blanked. The life of one of these bottoms varies from 18 to 25 "blows." The conditions which injure the bottom are low blast, a great depth of metal above the tuyeres, too much Al_2O_3 and Fe_2O_3 in the ganister mixture, and dampness of the repairing material. The bottoms are dried four days in a drying oven; several of these

are always kept on hand drying, for if not absolutely dry, they are useless.

"Acid" Converter Lining. Converters are lined with blocks of ganister with the joints faced with ganister mud. If pure ganister is used it is likely to give trouble on account of its expansion under heat. Too much Al_2O_3 causes the lining to melt out rapidly. The bottom is lined with a mixture of ground ganister and fire clay. Ganister, a flinty sandstone, is composed of about 98 per cent of SiO_2 with about 1 per cent or 2 per cent of $\text{Fe}_2\text{O}_3 + \text{Al}_2\text{O}_3$. The fire clay has about 86 per cent of SiO_2 , 10 per cent Al_2O_3 and 4 per cent of alkalies. If the manganese in the pig iron is less than $1\frac{1}{2}$ per cent the linings last for months. A high lime slag in the pig will rapidly flux

the SiO_2 of the lining. The nose section is lined with brick or stone and lasts but a short time.

The Casting Ladle. The general shape and arrangement of the casting ladle is shown in Fig. 8. The shell is made of iron plate and is lined with a layer of brick and upon this is pounded moist loam. The bottom G is made of rammed ganister material. The pouring hole is fitted with a cylindrical brick nozzle, with a hole 2 to 4 inches in diameter. The stopper A sets upon a bowl shaped seat. The stopper and stopper slide are shown in the figure. The end of this stopper, which fits the seat, is made of plumbago. The lining of the casting ladle lasts about 40 blows. A new nozzle and stopper is put in about every fourth blow.

Moulds. The moulds must be hard enough to withstand the strain caused by expansion and contraction when heated or cooled, yet not brittle. These moulds, if made of iron, have a composition as follows:

Silicon	1.7 per cent
Phosphorus	.1 per cent
Manganese	.75 per cent

Moulds are made of gray iron as white iron is too brittle. These moulds last about 90 operations.

INGOTS.

Method of Pouring. Great care is necessary in the pouring of ingots. They should be poured in such a manner as to prevent spattering, oxidation of the surface and injury to the mould. There are three principal methods: Top pouring, the most natural, bottom pouring, and a combination of top and bottom pouring. The greatest objection to ordinary top pouring is that of spattering and oxidation of the surface. These are partly overcome by the admission of the molten metal through a pipe which reaches nearly to the bottom of the mould. By mechanical means, this pipe slowly recedes, so that the distance between its end and the surface of the metal is nearly constant. If the mould is bottom poured, the metal at the bottom, being kept hot, has a tendency to thin the bottom and walls of the mould. If they become too thin they are likely to crack or burst. The slag has to

rise through the entire column of metal and if this becomes cooled particles of slag become entangled. Also, the slag has a tendency to solidify in the pipe by which the metal is introduced, thus causing poor ingots. The best results have been obtained from a combination of top and bottom pouring. During the first half of the time the metal is bottom poured and then finished by top pouring. In this case, the gases and slag have only a short distance to rise.

Shape of Ingots. Ingots are usually square with rounded corners slightly tapered to one end, so that they may be easily removed from the mould.

Gases and slag rise to the top of the ingot. Sometimes a "pipe" is formed in the center by the metal solidifying and shrinking away from the center. To prevent this the top is kept

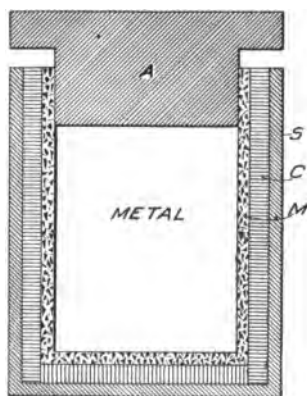


Fig. 9.

liquid longer by a covering of sand. It is advantageous to keep the cavity near the top, so that a large portion of the ingot will be sound. Another method is to cast ingots one on top of the other in a column, pouring one as soon as the preceding one has begun to solidify. This brings the cavity and imperfections in the last ingot. Another remedy is to cast the ingots longer than is necessary and cut off the top; but this is a waste of metal for the cut off portion has to be remelted and recast. Another way is to make the top rounding, in order to allow the impurities and gases to collect in the rounded part.

We learn from Chemistry that the solubility of gases in liquids increases with pressure; this principle is made use of in the casting of ingots. The mould is arranged as in the accompanying diagram, Fig. 9. The outside S is formed of steel in which is a thin layer C of perforated cast iron, the mould being lined with moulding sand M. The top plunger A is stationary. The mould is made to rise by powerful machinery. When the metal has begun to solidify the mould is raised until the pressure

becomes 10 to 20 tons per square inch; this pressure is kept on for about 20 minutes. The gases are not squeezed out by this process; the pressure tends to dissolve them. This process is used in making armour plate and gun tubes, but is too expensive for ordinary use.

Rail Making. Very soon after an ingot is poured it commences to solidify at the surface. A solid shell forms with a pasty or liquid interior. As the ingot cannot be rolled until it has become of uniform softness it is put in a "soaking pit." By means of currents of hot gases, the ingot soaks or equalizes, that is, it becomes uniform throughout. It soaks in these hot gases for about an hour. The ingot is taken from the soaking pit by an electric traveller, and is rolled down in the blooming mill to a "bloom" of about 7 inches by 7 inches in section, which, after the ragged edges have been cut off by hydraulic or steam shears, is finished, without re-heating, in a rail mill. Sometimes the bloom is allowed to partially cool and is then reheated before being finished. This process is expensive on account of the fuel and labor, but it reduces the number of defective rails. The whole ingot is rolled in the rail mill into one long rail, and this is cut into standard lengths by hot saws. After the rails cool they are straightened in steam presses and are then inspected and bolt holes drilled in the ends. Steel rails have the following composition:

Carbon,	.40 per cent to .6 per cent
Phosphorus,	.08 per cent to .1 per cent
Manganese,	.75 per cent to .9 per cent
Sulphur,	.05 per cent to .1 per cent
Silicon,	.05 per cent to .15 per cent
and sometimes Copper,	.01 per cent to .2 per cent

If the carbon is above .6 per cent the rail will be too brittle and will break under the drop test. In this test a heavy weight is allowed to fall through a specified distance on a piece of rail about 3 feet long, supported at the ends.

If the carbon is below .4 per cent the rail is too soft to stand the wear of the car wheels; if the phosphorous is above .1 per cent the steel will be "cold short" (brittle); if the manganese is much below .75 per cent the ingot will crack in rolling; if the

sulphur is above .1 per cent there will be short feathery cracks in the ingot when rolled, especially if rolled at a low red heat. Silicon up to .15 per cent improves the rolling qualities of the steel, but makes the steel brittle if the percentage of silicon is much higher.

The Bessemer process is also used in making soft steel. This steel is made into barbed wire, wire nails, hoop iron and sheets for tin plate and galvanized iron; it is also used for some structural steels and agricultural implements. This steel has about .1 per cent to .15 per cent carbon, and .4 per cent to .5 per cent manganese.

About 70 per cent of the steel made in the United States is Bessemer steel, and about 30 per cent of this is made into rails.

THE OPEN HEARTH PROCESS.

The Open Hearth Process for making steel is divided into three methods, according to the character of the material used. They are,

- 1, The Martin Process, in which pig iron and scrap are used.
- 2, The Siemens Process, or "pig and ore" in which pig iron and ore are used.
- 3, The Combination Process, using pig iron, scrap and iron ore.

The open hearth process was made possible by the invention by Siemens of the regenerative chambers, first successfully used by Martin, and is often called the Siemens and Martin process. The fuel is gas, which is burned on the hearth of a large reverberatory furnace. Both the gas and air are heated by the products of combustion in the regenerative chambers, as represented by Fig. 10. The heated gas and air enter the furnace on the left, burn on hearth H, and the products of combustion pass out and down through the chambers A and G on the right. These chambers are filled with fire brick set up with spaces between, called checker work, which becomes heated to a white heat. After a time the currents of gas and air are reversed and pass through the checker work just heated, becoming highly heated before they combine and burn, thus the heat is "regenerated."

The currents are reversed once every half-hour (to an hour)

and a very intense heat is maintained so that the metal in the condition of wrought iron is kept in a molten state.

In this country the combination process is generally used. With this process the scrap and pig iron are first melted. As this iron contains too much carbon, iron ore is added to reduce the percentage. This process, like the Bessemer, has two main divisions, the Acid and the Basic open-hearth processes, having siliceous and lime-magnesia linings respectively, and like the Bessemer process, only low phosphorous iron can be used with the acid lining while high phosphorous stock is used with the lime lining. In the

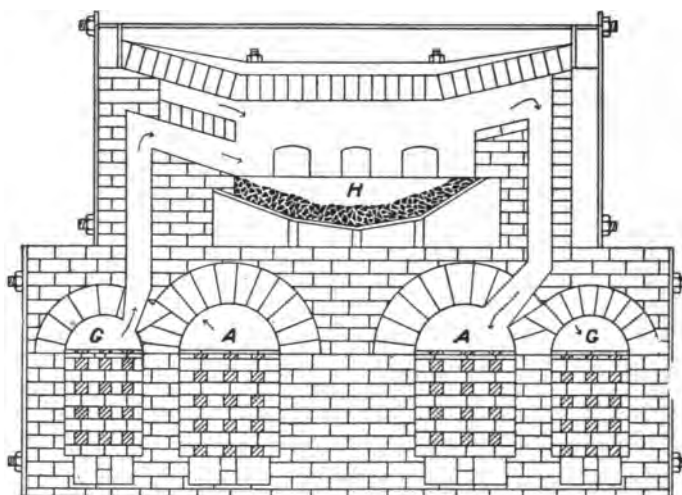


Fig. 10.

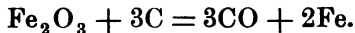
Bessemer process only medium and low carbon steels can be made, while in the open-hearth, steel of any grade of carbon can be made. This process also has the advantage of being more under control, and the product is more uniform, more reliable and contains less gas. Open-hearth steel costs about \$2.00 a ton more than Bessemer.

Open-hearth steel is used for making spring steel (carbon .8 per cent to 1 per cent) for cars and wagons; structural steel for bridges and buildings; steel for agricultural implements and tools; cast steel and mild steel (low carbon) for boiler plates (carbon .15 per cent, and phosphorus .03 per cent).

The Bessemer process and open-hearth process can be advantageously carried on together, as the scrap and "crop ends" of the Bessemer are largely used in the open-hearth.

MANAGEMENT, OR RUNNING THE ACID PROCESS.

At the start the furnace is heated by a wood fire, and then the gas is turned on and lighted. When the temperature is sufficiently high to melt steel, the charge is put in. It consists of one-third pig iron, and the rest wrought iron and steel scrap. On account of the low melting point of pig iron, one-half of the pig iron is put in first on the bottom. If steel or wrought iron were charged first, it would be slow in melting. The scrap is then put on and covered by the rest of the pig, and currents of air and gas are reversed at intervals, each time coming up hotter. In four hours it is all melted, but the carbon is too high, and it is not yet ready for casting. To expel this carbon small amounts of iron ore are added. CO is produced, which boils off.



This boiling continues until the desired percentage of carbon is reached, which is determined by sampling. These samples are taken out at intervals, cooled and broken; the percentage of carbon being judged by the appearance of the fracture. As the boiling down occupies three or four hours, there is time for an approximate chemical analysis. Manganese and silicon have both been absorbed by the slag, therefore some manganese must be added before casting. This is done by adding to the casting-ladle red-hot spiegel, or ferro-manganese, the size of peas. If steel castings are being made, a little silicon must also be added, to prevent blow-holes. When the steel is ready chemically, it is usually hot enough to cast. The furnace is tapped by driving a bar through the tap-hole, and the molten metal flows out of it into the casting-ladle, which is similar to that of the Bessemer process. The casting is done in moulds, as in the Bessemer process. Bottom pouring is often employed, especially if the ingot is to be made into steel plate. The bottom of the mould has to be repaired after each operation.

MANAGEMENT OR RUNNING THE BASIC PROCESS.

The furnace used is very similar to that of the acid process, except for the lining, which is of dolomite or magnesite. Dolomite is hard-burned lime made from a magnesia limestone. Magnesite is made from MgCO_3 , calcined several times at high heat. Layers of dolomite or magnesite, mixed with 10 per cent of boiled tar, is rammed in with hot rammers all over the bottom and sides, above the slag line. Upon this hearth, scrap and high phosphorous pig iron are melted down. To prevent fluxing of the lime lining, limestone is spread over the bottom before charging. After melting there is too much phosphorus and carbon in the charge. These elements are oxidized by the addition of the iron ore. The agitation and boiling of the phosphoric bath is caused by the escaping gas, CO, and the metal is thus brought in contact with the basic slag and the phosphorus removed. If all the phosphorus is not out at this point, pig iron is added to raise the percentage of the carbon, and the bath is again boiled down. The appearance of the fracture of the sample indicates the amount of phosphorus present. If there is a large amount, two cross-lines of bright crystals, called the "Phosphorus Cross," appear in the center. The casting is the same as in the Bessemer process. The wear of the basic lining is greater than that of the acid, especially if the silicon is high. Holes in the hearth are repaired after each heat.

The tap-hole is rammed with tar dolomite or magnesite.

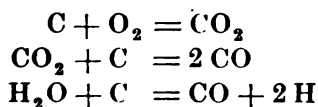
In an ordinary open-hearth furnace only two heats can be made in a day. The charge varies from 10 tons in a small furnace to 50 tons in a large one.

Tilting furnaces are being used in modern plants, which lessen the time of charging and working, and "direct metal" from mixers is used in place of pig, which further reduces the time. Altogether, the open-hearth process is gaining in favor in this country. The basic process is more used than the acid, because high phosphorous pig is cheaper.

GAS PRODUCERS.

Gas is the fuel used in the open-hearth process. The Siemens Gas Producer is now little used, most gas being made by the

Wellman Gas Producer. Fig. 11 is the sectional view of this producer. A forced draft, usually a steam-jet injector, supplies steam and air to the furnace under slight pressure. The following reactions take place when air or steam unite with coal:



The resulting producer gas has about the following composition:

Nitrogen,	60.3 per cent
Carbon Monoxide,	22.8 per cent
Carbon Dioxide,	5.2 per cent
Oxygen,	0.4 per cent
Hydrogen,	8.5 per cent
Hydrocarbons,	2.8 per cent

In running the producer, there is a heat loss of about 35 per cent, principally in radiation, ashes, latent heat, decomposition of steam, and sensible heat of gas. Another producer, the Taylor Producer, has in place of the grate-bars a revolving dome-shaped plate, through which air is driven into the center of the fire. In place of the brick lining this producer has a water-jacket. Bituminous coal is the fuel generally used in these producers. As this gas contains about 60 per cent nitrogen, it is weak fuel. In a few localities natural gas, a stronger fuel, is obtained. A gas made of vaporized petroleum mixed with dry steam and forced through a red-hot metallic retort, is used in the Archer process.

SPECIAL STEELS.

Nickel Steel. Nickel steel is made by adding metallic nickel, nickel ore, or ferro-nickel, to the bath of the open-hearth process. The nickel increases its density, elasticity and strength. This steel is used for armour plate, on account of these qualities, and also because it does not corrode. Nickel steel contains about 4 per cent nickel, .3 per cent carbon, .7 per cent manganese, and .02 per cent phosphorus. For such uses as bicycle tubes, shafts, axles, etc., the high elastic limit of nickel steel tends to prolong indefinitely the life of the piece, and because of its superior toughness, offers greater resistance to sudden strains and shocks.

Aluminum Steel. From .05 per cent to .1 per cent aluminum in steel castings reduces the melting point, prevents blow-holes, and keeps the metal liquid while being poured. Aluminum gives no increase of hardness.

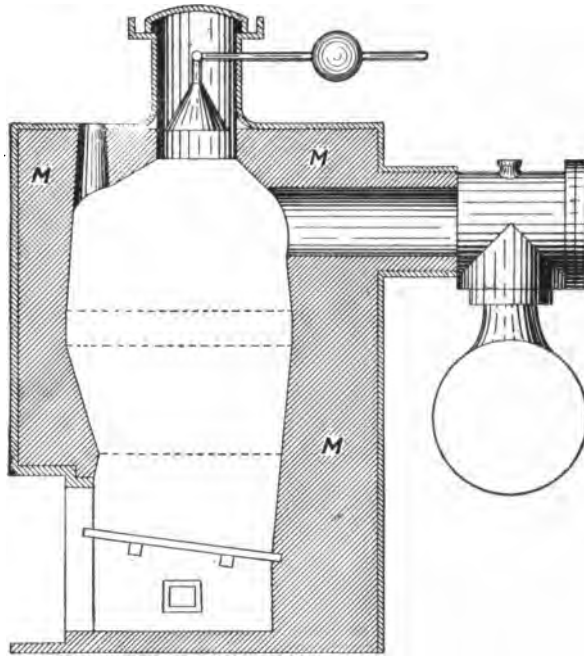


Fig. 11.

Chrome Steel. If chromite is melted in brasque crucibles with charcoal, the result, ferro-chrome, which has 40 per cent chrome and 48 per cent iron, is used in making chrome steel, by melting it with bar iron in crucibles. Chrome, like manganese, hardens iron. It also makes it more forgeable. It is used, on account of its hardness, for burglar-proof safes, but it is not entirely satisfactory, and other steels are fast driving it out. It has about the following composition: chromium, .5 per cent to 3 per cent; carbon, .5 per cent to .9 per cent.

Manganese Steel. Manganese steel is an alloy of iron and manganese, containing a considerable proportion of carbon. It

there is a very small portion of manganese, the effect is slight. As the proportion of manganese rises above 2.5 per cent the strength and ductility diminish, while the hardness increases. This hardening effect is a maximum with about 6 per cent manganese. Above this the strength and ductility both increase, and at 14 per cent of manganese the metal is so hard that it is difficult to cut with steel tools. It welds with great difficulty, but it can be forged. Its toughness increases by quenching from a yellow heat. It has a remarkable combination of great hardness, which cannot be lessened by annealing, great tensile strength, toughness and ductility. The fact that it cannot be machined, on account of its hardness, limits its usefulness. It is used principally for car-wheels, dies and crusher-jaws.

Tungsten Steel. Steel containing a little carbon and tungsten is much harder than steel with carbon alone, and yet not very brittle. A specimen from Sheffield, England, for chisels, used untempered to turn chilled rolls, was not brittle, yet it was hard enough to scratch glass. It contained 9.3 per cent tungsten, .7 per cent silver and .6 per cent carbon. In working this metal it has to be given its final shape by hammering at red heat, and if the percentage of tungsten is high it is necessary to reheat it while it is being hammered. After the desired shape is reached the hammering must be continued, with numerous blows, until it becomes nearly cold. Tungsten is employed to produce steel of moderate hardness, with great toughness, resistance and ductility. Its principal use is for cutting-tools. It is self-hardening.

CASE-HARDENING.

By the process called case-hardening, a thin layer of steel is formed over the iron. To do this, iron is heated to redness, and powdered potassic ferro-cyanide $K_4Fe(CN)_6$, is sprinkled over the surface. When suddenly cooled, the surface of the iron is hard enough to resist a file. The chemical reaction which takes place is



THE HARVEY PROCESS.

The Harvey process for making armor plate is somewhat like case-hardening. The outside of the heated steel plate is cov-

ered with charcoal, from which it absorbs carbon in the same manner as wrought iron absorbs carbon in making cement steel. The layer of hard steel thus formed is further hardened by quenching with water. This makes a plate with an exceedingly hard surface, which breaks up shot and shell. The backing is, however, tough, mild steel.

THE EFFECTS OF THE ELEMENTS IN STEEL.

The following from Howes' Metallurgy of Steel will give an idea of the effects of the elements :

Carbon. Carbon up to 1.5 per cent increases Tensile Strength, Compressive Strength, and raises the Elastic Limit; decreases the malleability and welding power.

Silicon. Silicon increases hardness, Tensile Strength and solidity, and prevents blow-holes. Too much silicon makes steel brittle. From .3 per cent to .5 per cent should be the maximum.

Sulphur. Sulphur causes hot shortness; that is, the metal is brittle when hot, both under the hammer and rolls.

Arsenic has the same effects as sulphur.

Phosphorus causes cold shortness. It makes steel hard and liable to break. It increases the Elastic Limit and reduces Elongation.

Manganese prevents hot shortness and blow-holes, removes or offsets the effect of sulphur. It increases Toughness, Elongation and Tensile Strength. Too much manganese makes steel brittle when cold, especially after quenching.

Copper. Copper causes red shortness; .5 per cent may be allowed in rails, but 2 per cent makes steel worthless. Tin steels are not forgeable or ductile, either hot or cold.

TEMPERING.

Tempering steel is the process of giving it, after it has been shaped, the necessary hardness to do its work. A piece of steel after it has been properly tempered should be finer in grain than the bar from which it was made.

This is accomplished by first hardening the piece, usually harder than necessary, and then toughening it by slowly heating and gradually softening, until it is just right for the work. The

process is as follows: The tool to be tempered is heated to a cherry red, and plunged into cold water or oil to a depth somewhat above the cutting edge. When this portion has become entirely cold, the piece is taken out and the cold end polished, usually with emery-cloth; the point is now too hard and brittle. The heat contained in the hot portion gradually enters by conductivity into the quenched part, and as it does so, colors are formed which denote temperature. The colors seen in order are pale yellow, straw, brownish yellow, light purple, dark purple, blue. They are formed by oxide on the surface. These colors run from the hot portion to the cutting edge, and when the proper color reaches the cutting edge, the whole piece is quenched. Some tools are of such a shape that the temper must be "drawn" to the desired color by reheating the piece between hot plates or in a hot iron ring.

The following list will give some idea of the colors, temperature and hardness of tools:

Very pale Yellow, temperature about 430° F.	{ Steel-engraving Tools. Turning Tools. Hammer Faces. Planer Tools. Wood-engraving Tools.
Straw Yellow, temperature about 460° F.	{ Dies. Taps. Drills. Punches. Reamers.
Brown Yellow, temperature about 500° F.	{ Gouges. Plane Irons. Twist Drills. Cooper Tools. Wood-boring Cutters.
Light Purple, temperature about 530° F.	{ Augers. Surgical Instruments. Cold Chisels. Edging Cutters.
Dark Purple, temperature about 550° F.	{ Axes. Gimlets. Needles. Hack Saws. Screwdrivers. Springs. Wood Saws.

COPPER.

As copper occurs in the metallic state, it was one of the earliest known metals. The native copper deposits of the Lake Superior region were worked by prehistoric inhabitants. Copper compounded with tin was the metal of the Bronze Age. With the exception of iron, copper is our most useful and important metal.

ORES.

The native copper of Lake Superior is still an important source of supply, but by far the largest quantity is obtained from the sulphide ores, of which Copper Pyrites ($\text{Cu}_2\text{S} \cdot \text{Fe}_2\text{S}_3$) is the most important. When pure it contains 34.6 per cent of copper, 30.57 per cent iron and 34.9 per cent sulphur, but the average ore carries only about 12 per cent of copper. Spanish iron pyrites is another source of supply; it is first used in the manufacture of sulphuric acid, after which the copper is extracted from the "cinder." It contains only 3 or 4 per cent of copper, but carries also a small proportion of gold and silver, which makes it a profitable ore.

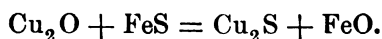
Carbonate ores, formed by the weathering of the sulphides are now about exhausted, as they occur only a short distance below the surface.

EXTRACTION.

There are two main processes for extracting copper from its ores:

- (1) Process involving fusion.
- (2) Wet process used for low-grade ores.

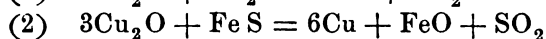
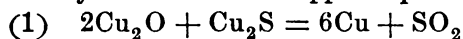
The most important fusion method is the "Welch" or "Reaction" process. The prepared sulphide ore is first roasted in heaps, kilns or a reverberatory furnace. Care is taken that not too much of the sulphur is expelled. Next, this calcined ore is fused in a reverberatory furnace. The copper has a greater affinity for the remaining sulphur than any of the other metals, and copper sulphide is formed.



The ferrous oxide (FeO) and the silica unite and form a slag, which carries away lime or other impurities present. The cuprous sulphide Cu_2S combines with the excess of iron sulphide

left in the charge, forming a fusible substance called a "regulus," or first copper matte, which contains about 30 per cent of copper. This first matte is again roasted and fused, and part of the iron slagged away as before, leaving the second matte, which contains about 50 per cent, if "blue metal" is wanted, or 75 per cent of copper, if "white metal" is being made. A small amount of metallic copper is also produced. These copper bottoms contain most of the impurities, including much of the gold and silver.

In a third reverberatory furnace the second matte is again partly oxidized and then fused, the product this time being crude metallic copper and a slag rich in copper. The rich slags from the first and second matte are worked up for their copper. The reactions by which metallic copper is produced are:



The SO_2 gas passes away and the FeO goes into the slag.

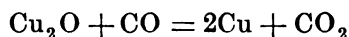
Producer gas is used for heating the furnaces in modern plants.

CUPOLA SMELTING.

In the first stages of this process the chemical action is about the same as the "Welch" method. A first and second "Matte" is produced in small water-jacketed blast furnaces of rectangular sections using cold blast. (See Fig. 12.) Some "black copper" is produced with the second matte.

The second matte, called "white metal," is now completely roasted to oxide. This oxide of copper is reduced to metallic copper in a blast furnace by CO gas in the same manner as in the production of iron.

The reaction is



The fuel is coke or charcoal. The slag from the first matte is thrown away, but the other slags go back into the process.

Less skilled labor is necessary in the cupola method and less fuel is required. It is consequently in favor in remote regions. The metal of oxidized ores (carbonates) can be extracted by this process in one operation. The reverberatory method produces purer copper, and must be used when there is much antimony and

arsenic in the ore. Highly refractory ores, which are difficult to fuse in a blast furnace, can be better treated in reverberatories, as the slag can be skimmed off in a partly melted condition.

The variations in the foregoing processes are numerous. A common American practice is to use the cupola for obtaining the first matte, and finish the process in reverberatory furnaces.

Modified Bessemer converters are now successfully used to convert copper matte into crude copper. The converter has the tuyeres in the sides, and is lined with silica and clay. As the

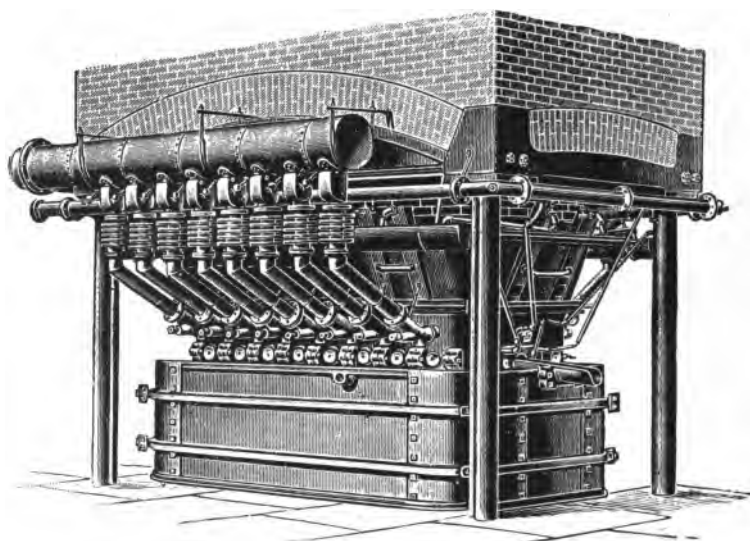


Fig. 12.

wear on the lining is very great, provision is made for quickly replacing a worn-out converter by one which has been relined. Mattes containing from 30 to 60 per cent copper have been thus successfully treated at a considerable saving of expense.

REFINING.

The crude copper produced by any of the foregoing methods is refined in a reverberatory furnace with a large hearth. It is slowly melted down with an excess of air. The impurities oxidize first and form a slag with the silica from the lining of the furnace. This slag is frequently skimmed off. The copper finally begins to oxidize, forming Cu_2O , which acts on any Cu_2S ,

forming SO_2 , which causes the molten metal to boil. When this action ceases, the copper contains too much copper oxide. This is reduced by "poling." Poles of green wood are thrust into the bath, and the distilled hydrocarbon gases cause the bath to boil, which expels any SO_2 gas remaining. Charcoal is spread over the molten metal, which, with the hydrocarbon gas, removes the oxygen from the Cu_2O , leaving metallic copper. Samples are taken out from time to time, and when the color changes from red to flesh color, and the sample becomes fibrous with silky lustre and can be bent double, the refining is finished. The rich slags go back into the process. A little oxide of copper is left in the metal, as it neutralizes the effect of the small amount of remaining impurities.

The metal is then run into small moulds. An ingot "under poled," containing too much oxide, will show a furrow along its surface. An ingot with the right proportion will have a flat surface, called "tough pitch," and one which is "over poled," containing too little oxide, will show a ridge.

Electric refining is fast replacing this older method. In the United States two-thirds of the product is thus refined. By the electrical method all the gold and silver in the copper is recovered, and the copper produced is very pure. The crude copper is cast into slabs as it runs from the furnace. A row of slabs is placed in a tank containing a solution of copper sulphate made acid with sulphuric acid. These form the dissolving plates, and opposite each is placed a thin sheet of pure copper. The tanks are connected in series by wires and the current passed through. The electric current causes the crude copper to dissolve and pure copper to be deposited on the thin plates. The gold and silver, together with other impurities, fall to the bottom as mud or "slimes," from which the precious metals are extracted by chemical processes.

The *wet process* is used for lean ores. It has the advantage of extracting at the same time any gold and silver present. This process involves getting the copper and precious metals into solution either as sulphate or chloride and then the copper is precipitated by electrolysis, metallic iron or quicklime.

The solutions are produced either by dissolving in the dilute

acids or roasting the sulphide to sulphate or by roasting with salt to obtain the chloride and then leaching with water.

PROPERTIES OF COPPER.

Copper is a rather soft metal and is very ductile and malleable. It can be worked both hot and cold, but should not be heated too hot, as it crystallizes and takes up oxygen. When worked cold it is stronger and harder, but less ductile. Heating and quenching make it softer. Rolled sheet copper has a tensile strength of from 24,000 to 28,000 pounds per square inch, and annealed wire over 40,000 pounds per square inch. Good castings cannot be made from pure copper because they contain blowholes and the shrinkage is too great.

Copper is not affected by the weather, but in damp places it is slowly corroded; carbonate of copper, called verdigris, being formed by the carbonic acid of the air.

The thermal conductivity of copper is high.

The electrical conductivity of good copper is but little less than that of silver, and is about six times that of iron. A very small amount of impurity reduces its electrical conductivity as much as 10 per cent. Antimony is the most harmful impurity from a mechanical standpoint, and should not be over .02 per cent.

The growth of electrical industries has greatly increased the demand and price of copper of late years. It is estimated that 60 per cent of the world's production of copper is consumed in electrical work. The United States produces over 55 per cent of the world's output of copper, or over a quarter of a million long tons annually.

LEAD.

The most important ore of lead is Galena, lead sulphide (PbS). In the United States it is found in the upper valleys of the Mississippi and Missouri Rivers and in the Rocky Mountains. The mines of Spain, Germany and England furnish the bulk of the European product. It occurs in bright, shining, cubic crystals of metallic lustre. When pure it contains 86.6 per cent of lead. Galena usually contains silver, and frequently a small amount of gold. It is associated with sulphides of zinc, antimony, copper and iron. As it is a very heavy mineral it is easily concentrated.

Cerussite — lead carbonate, PbCO_3 , — is an ore of some importance and is mined in Leadville, Colorado.

SMELTING.

Lead ore is smelted either in reverberatory furnaces or blast furnaces. When using the reverberatory furnace with sulphide ore, the chemical action whereby lead is produced is much the same as in the final stage of copper smelting in the "Welch" method. The ore is partially oxidized to lead oxide, PbO , at a low heat, some sulphate, PbSO_4 , also being formed. Then the temperature is raised and the lead is produced according to the following reactions:



The lead as it is formed runs into a pot, and the operation is repeated until no more lead can be extracted, when it is tapped and the slag withdrawn in a pasty condition. This "gray slag" is usually smelted in a blast furnace for the lead it still contains. This method is simple and the apparatus inexpensive, but its use is limited to high-grade ores containing 60 per cent to 70 per cent of lead, and only 4 or 5 per cent silica. The process requires much fuel and skilled labor.

SMELTING IN A CUPOLA OR BLAST FURNACE.

This process is used for all ores containing over 4 per cent silica, for carbonate ores, and for various lead slags and drosses obtained in purifying the crude lead.

The Furnace is built of brick and lined with fire brick. It is usually oblong in section. The shaft is from 14 to 20 feet high and tapers downward to the boshes, which taper more sharply to the crucible. The section at the crucible is usually about 12 feet by 3 feet 6 inches. The tuyeres, 6 or 8 in number, are placed on each side, near the top of the crucible. The boshes and part of the crucible are cooled by cast or wrought iron water jackets. The furnace is charged through a door in the side, near the top.

As lead is somewhat volatile, provision must always be made for collecting the lead fumes. Various devices have been tried, but long flues, wherein the fumes condense and settle, are most

commonly used. The top of the furnace is connected with one of these flues.

The sulphide ores are roasted in a reverberatory furnace or in hand or mechanical kilns. The roasted ore is charged into the blast furnace with suitable fluxes and various mixtures of coke, charcoal and coal as fuel. Iron plays an important part in the smelting, as it is capable of decomposing silicate of lead and is added as an iron slag or as ore if not present in correct amount.

In smelting there is usually a small amount of matte formed, consisting of sulphides of iron, copper, nickel and lead. This is tapped with the slag into a slag pot, where it rises to the top and is separated when the mass cools. The matte is broken up and roasted and its lead and copper recovered. The lead collects in the crucible and is tapped out at intervals.

SOFTENING AND DESILVERIZING.

The lead obtained by either the reverberatory or blast furnace method contains copper, arsenic, antimony and other metals in addition to silver. The impure lead is slowly melted down in a reverberatory furnace. The lead, having a lower melting point than the impurities, liquefies first, leaving a residue containing the copper and part of the arsenic and antimony. The lead is next heated very hot with an excess of air, and then most of the remaining impurities oxidize and form a scum, which is skimmed off. The silver remains with the softened lead and is extracted by the Park's Process. This process depends upon the fact that a small percentage of zinc added to the molten lead will collect all the gold and silver to form an alloy, which, being of less specific gravity, rises to the top, and having a higher melting point solidifies before the lead.

From the softening furnace the molten lead is run directly into a large kettle. Here from 1 to 3 per cent of zinc is added to three successive portions. After each addition the mass is well stirred and then allowed to cool somewhat, when a crust is formed, which is removed. The first crust contains most of the gold and is called the gold crust. The second crust is called the silver crust, and the third crust, containing the silver that still remains, is used for the first addition to the next charge.

RECOVERY OF THE SILVER AND GOLD.

The gold and silver crusts are melted slowly in a kettle or reverberatory furnace, and most of the lead mixed with the crust melts out and is recovered. The zinc is distilled off in large graphite retorts, leaving a small amount of lead, which contains all of the silver and gold. The lead is separated from the precious metals by cupelling. In the cupelling furnace the lead is oxidized to litharge (PbO), leaving the metallic silver and gold. The furnace has a hearth made of porous material, which absorbs part of the melted litharge as it forms; the remainder runs into a pot. The litharge is ground and sold if it does not contain too much silver, in which case it is smelted again. About 60 per cent of zinc is recovered in metallic form and is used again in the desilverizing kettle.

REFINING THE DESILVERIZED LEAD.

The desilverized lead contains .6 per cent to .7 per cent of zinc, which is removed in a reverberatory furnace or large kettle. The charge is heated very hot in the reverberatory, and the zinc in part volatilizes; then the doors are opened and the remainder of the zinc is oxidized, and with some lead oxide is skimmed off. This is repeated until the zinc is entirely removed.

When refined in a kettle, steam is forced into the molten charge; the zinc and a little lead oxidize and form a scum, which is skimmed off.

The desilverized and refined lead is run into iron molds on wheels, and when cooled is ready for the market. The amount of marketable lead obtained is about 80 per cent of the impure lead. By using the Howard "stirrer," "skimmer" and "press" for the gold and silver crusts, 85 per cent has been obtained and 70 per cent of the zinc recovered.

An older process for desilverizing lead is the Paterson Process. It is found that when molten lead is cooled slowly, crystals of lead form which contain less silver and other impurities than the remaining molten mass. By repeated crystallization the silver is concentrated in a portion of the lead, and the remainder is almost free from silver. The silver-bearing portion, which must be cupelled, is about 30 per cent of the whole against 5 per cent in

the Park's Process. The Paterson Process is not used in the United States.

The working up and recovery of all the by-products formed in the smelting of lead is a very important and very complex part of the process.

PROPERTIES OF LEAD.

Lead is the softest and heaviest common metal. It is very malleable and ductile, but has little tenacity. Lead is insoluble in sulphuric acid of moderate strength and is not much affected by cold hydrochloric acid. It is used in chemical works in the manufacture of sulphuric acid and for other purposes. Ordinary water has little effect on lead. Pipes used for conveying water are soon covered with a thin layer of carbonate and sulphate of lead, which is insoluble and prevents further action.

Water from swamps, etc., however, dissolves small amounts of lead, which makes its use dangerous for domestic purposes. Water from new pipes or pipes which are not kept constantly full should not be used for household purposes, because of danger from poisoning.

Lead is not affected by dry air, but is slowly corroded in moist air.

TIN.

This metal was known to the ancients, and very successfully used by them for hardening copper. The most important ore is tin-stone, Sn O_2 , and the principal mines are in Cornwall, England, and Banca in the East Indies.

The smelting is conducted in a reverberatory furnace. The concentrated ore, mixed with finely divided anthracite coal and with a little lime is heated on the bed of the furnace. The tin is produced and runs into the depressed center of the furnace, from which it is tapped and cast into pigs. This impure tin is refined by liquating and poling.

PROPERTIES AND USES.

Tin is white in color with a slightly yellowish shade. It has a peculiar odor, and when bent it gives out a crackling sound known as the "tin cry." It has little tenacity, considerable ductility, and is very malleable. It can be worked at about the

boiling point of water, but becomes very brittle at 400° F. It can be rolled into very thin sheets; tinfoil being sometimes only one-thousandth of an inch thick. On account of its ductility it is readily made into tubes, wire, etc.

The bulk of this metal is used for tin plate. Thin sheets of mild steel are carefully cleaned and annealed and then dipped in a bath of molten tin covered with a layer of tallow. They are then passed through rolls to remove the superfluous tin, leaving a very thin coating of pure tin on both sides of each sheet. Tin plate finds numerous uses in the canning industries, for household utensils, etc.

Almost all of the remaining product is used for making alloys of tin, and only a comparatively small amount is used for pipes, sheets, etc., on account of the high price of this metal.

ZINC.

A large proportion of this metal is obtained from the ore called Zinc Blend, ZnS ; the carbonate and silicate are also important ores, and considerable zinc is obtained from Franklinite.

In the metallurgy of zinc advantage is taken of the volatility of this metal. It can be distilled unchanged at 1040° F. The ore is roasted to oxide of zinc, ground and mixed with finely divided fuel and heated to a bright red in gas heated retorts. The carbon takes the oxygen from the zinc oxide, forming CO gas, and the zinc is set free and distills off. It is condensed in iron tubes which are kept at such a temperature that the zinc remains liquid and runs into a receiving vessel.

This zinc contains iron and other impurities, and is purified by redistillation. It comes on the market cast in slabs, and in this form is called "spelter."

PROPERTIES AND USES.

Zinc is a bluish white metal, brittle and crystalline. It is quite ductile at a temperature of 248° F., but is so brittle at 390° F. that it can be crushed to powder.

Zinc is readily dissolved by acids and alkalis, but is not affected by the weather. It is very largely used for galvanizing iron, which is done by dipping the carefully cleaned iron in a bath of molten zinc, using sal-ammoniac as a flux. Zinc protects

the iron from oxidation, and is effective as long as any zinc remains on the iron, being the reverse of the action of tin plate which causes the iron to rust more quickly as soon as there is any flaw in the coating. Zinc is also used in making alloys and for batteries, sheets for roofing, etc.

ALUMINUM.

Aluminum has recently been transferred from a rare metal to one which, bulk for bulk is no more expensive than copper, by an electrolytic process invented by Hall. Beauxite, a hydrated oxide of aluminum is the important source of supply. Hall's process is conducted in a graphite lined vessel, and depends upon the property of cryolite — a double fluoride of sodium and aluminum, of dissolving fused oxide of aluminum. Cryolite melts at about 900° F. and then becomes a conductor of electricity. The bath is kept in a molten condition by a heavy current of electricity of low voltage. The oxide of alumina is sprinkled on the top of the bath and quickly dissolves, and is reduced by electrolysis to metallic aluminum which settles in the bottom of the crucible, from whence it is drawn from time to time.

If pure aluminum is desired the oxide of alumina used is obtained by a chemical process from beauxite.

PROPERTIES AND USES.

Aluminum is a grayish white metal, very malleable and ductile, and is a good conductor of both heat and electricity. It is acted on but feebly by sulphuric or nitric acid or by the organic acids. It is, however, dissolved by hydrochloric acid and the alkalies. Its most remarkable property is its extreme lightness, it being only about one-third as heavy as iron. It is fairly strong and imparts great tensile strength to its alloys. Good castings can be made from it, although the shrinkage on cooling is considerable. It can be worked cold, and is readily formed into sheets, wires, tubes, etc.

It is replacing copper to some extent as an electrical conductor, and is used for making a high class of kitchen utensils and a great variety of small ornamental articles. One objection to its use for some purposes is that it can be soldered only with difficulty.

Aluminum has not fulfilled the enthusiastic prophecies which were made when it became a common metal. Among the reasons for this may be mentioned its low tensile strength and unreliability. It is not as strong, weight for weight, as steel, and is too soft to resist wear. Again, continued shocks render it crystalline and brittle; consequently unreliable. Its expansion and contraction for heat and cold is considerably greater than in the case of copper, and great care must be taken in putting up lines of wire made of this metal. It is more easily corroded by sea water than copper; and its position in the electrical scale of metals is such that when any other metal comes in contact with it the aluminum is corroded.

The table on page 49 gives in a condensed form some of the more important properties of common metals. This table is a great aid in making calculations for weights, strength, etc., and also gives an idea of the relative cost. Many of the various properties are subject to some variation. The specific gravity varies with the percentage of foreign substances, and also with the process of manufacture, that is, whether the metal has been rolled, hammered or cast. The melting points of commercial metals are also somewhat variable.

TABLE OF METALS.

NAME.	Specific Gravity.	Melting Point. Fahrenheit.	Electrical Con- ductivity. Silver = 100.	Heat Conductiv- ity. Silver = 100.	Tensile Strength. lbs. per sq. in.	Weight per cu. in. in lbs.	Weight per cu. ft. in lbs.	Approximate Price per pound in Pigs, Billets, etc., 1902.
Cast iron	7.0 to 7.7	2100°	12.0	11.4	13,000 to 30,000	.260	445	3 ¢
Wro't Iron	7.4 to 7.8	3000°	16.0	11.9	40,000 to 60,000	.278	485	1 ¢
Steel 0.1% C.					50,000 to 65,000			
“ 0.2% “					60,000 to 80,000			
“ 0.4% “	7.6 to 7.8	2500°	12.0	11.6	70,000 to 100,000	.283	490	1 ¢
“ 0.6% “					90,000 to 120,000			
Copper	8.8 to 8.9	1930°	99.9	73.6	25,000 to 50,000	.320	555	14¢
Lead	11.2 to 11.4	620°	8.3	8.5	1,600 to 2,400	.410	709	4 ¢
Tin	6.9 to 7.3	446°	15.0	14.5	3,000 to 5,000	.263	455	25¢
Zinc	6.8 to 7.2	774°	29.0	19.0	5,000 to 20,000	.258	446	4 ¢
Aluminum	2.56	1100°	63.0	38.0	12,000 to 23,000	.093	160	30¢
Bronze	8.7	1550°	6.5		29,000 to 60,000	.313	541	20¢
Brass	8.4		22.0	23.6	30,000 to 40,000	.300	519	13¢

ALLOYS.

Mixed metals give us alloys, many of which possess useful and valuable qualities not found in the pure metals. The ancients were skilled in making bronze and brass, and many of their products cannot be surpassed at the present day.

In general the alloys of copper with tin are known as bronze, and with zinc as brass, but zinc is frequently added to bronze to cheapen it or change the color, and tin is often added to brass to harden it, so that the line between them cannot be sharply drawn.

There are countless combinations of metals, but only a few are of general importance. The table given includes most of these with their approximate composition, although each foundry has its own special mixtures. In making alloys, the most infusible metal is melted first, and the others are dropped into the crucible in small lumps, the most volatile being added last. A layer of charcoal is frequently thrown on the surface of the metal to prevent oxidation. In many alloys the metals begin to separate on standing, in which case it is necessary to mix well and pour at as a low temperature as possible, so that the casting will solidify quickly. This is helped by casting in iron moulds. Some metals can not be alloyed in all proportions; thus copper will take up only a small proportion of lead.

To produce finest quality alloys only pure metals can be used, as small amounts of impurities have a very decided effect, just as in the case of iron and copper. The method of making is also important in determining the quality of an alloy. In general alloys which are to be worked into sheets, tubes and wires must be more pure than those required for castings. A small proportion of lead is said to help the rolling qualities of brass, and a very small percentage of phosphorus in bronze makes it more fluid and free from blow holes. The alloys of metals with mercury are called amalgams. One method of extracting metallic gold from its ores is amalgamation, and the effect of amalgamating the zinc in batteries is well known. Formerly alloys were thought to be chemical combinations of metals, but now it is generally considered that they are simply mixtures of metals, sometimes being solidified solutions in each other.

TABLE OF ALLOYS.
Approximate Percentage Composition by Weight.

NAME.	Copper.	Tin.	Zinc.	Lead.	Other Metals.	USES AND REMARKS.
Gun metal	91	9				Ordinance, bearings, castings
Bell metal	75	25				Bells, gongs; rather brittle
Bronze coin	95	4	1			Coins, medals
Phosphor bronze	92½	7			½ Phosphorus	Strong castings, heavy bearings
Manganese bronze	89	10			1 Manganese	Propeller blades, pumps. It is non-corrosive and very strong
Aluminum bronze	90				10 Aluminum	Very high tensile strength
Valve metal (best)	88	12	2			Sometimes called "composition"
Valve metal	83	2	15			Cheaper valves, cocks, etc.
Bearing metal	77	8		15	Trace of Phosphorus	Heavy bearings, used on railroads
Brass (common)	66⅔		33⅓			Sheets, wire, tubes, pipe fittings
Muntz metal	60		40			Bolts, nuts; malleable at red heat
Delta metal	56		42		2 Iron	Strong sheets, etc; "Tobin bronze" is a delta metal with a little tin and lead added.
Brazing metal (soft)	50	12½	37½			Low melting point
Brazing metal (medium)	50		50			For copper work
Brazing metal (hard)	75		25			Strongest
German silver	60		20		20 Nickel	Ornaments, resistance wire; composition variable
Fusible plug		10		86	4 Bismuth	For steam boilers
Common solder		50		50		
Fine solder		66⅔		33⅓		
Babbitt's metal	3	89			8 Antimony	The original Babbitt; for bearings
Babbitt's metal				80	20 Antimony	Commonly called Babbitt; used for repair work on bearings
Pewter		80		18	2 Antimony	Plates, mugs, etc.; composition variable
Britannia metal		90			10 Antimony	Table wear, ornaments; composition variable
Type metal				80	20 Antimony	Type and lithograph
Regulus metal				88	12 Antimony	Acid cocks, valves, etc. Sometimes called white metal.

EXAMINATION PAPER.

METALLURGY.

Read carefully : Place your name and full address at the head of the paper. Any cheap light paper like the sample previously sent you may be used. Do not crowd your work, but arrange it neatly and legibly. *Do not copy the answers from the Instruction Paper: use your own words, so that we may be sure that you understand the subject.* After completing the work add and sign the following statement:

I hereby certify that the above work is entirely my own.
(Signed)

1. What is blister steel? How is it made?
2. What takes place when cast iron is made into wrought iron? Name the principal process.
3. Name three ores of iron with their approximate percentages of iron.
4. Why is the percentage of silicon important in iron castings?
5. What are the advantages of the Bessemer process of making steel? Of the Open Hearth process?
6. Explain the process for reducing iron ore to metallic iron. Give reaction.
7. What is the advantage of heating the blast of the blast furnace?
8. By what method is wrought iron made directly from the ore?
9. Give some of the qualities of pig iron. What chemical elements does it usually contain?
10. Why has mild steel replaced wrought iron? Why is wrought iron more easily welded than mild steel?
11. What is flux? What is slag?
12. Why does pig iron make good castings?
13. What is spiegel? State its use and approximate composition.
14. Describe briefly the Bessemer converter.

METALLURGY.

15. Of what is the lining made in the "acid" Bessemer converter?

16. Describe briefly the process of tempering. What color denotes the hardest temper?

17. What is the influence of manganese on pig iron? On steel?

✓ 18. Why is steel made in the crucible superior to both Bessemer and Open Hearth steels?

19. How is the melter able to judge when the Bessemer converter charge is ready to pour?

20. State some of the qualities of nickel steel. How is it "face hardened" in making armor plate?

21. What fuel is used in the Open Hearth process? Why?

22. What are Siemens regenerative chambers?

✓ 23. How is carbon expelled in the Open Hearth process? Write and explain the chemical reaction.

24. Describe briefly the blast furnace.

25. What is self hardening steel?

26. What fuel is used in the blast furnace?

27. What is the most important ore of lead? Of copper? Of tin? Of zinc?

28. What is a copper matte?

29. A piece of boiler plate (mild steel) is $\frac{7}{8}$ inch thick, 2 feet wide and 3 feet long. How much does it weigh?

30. Find the weight of zinc in 48 cubic inches of brass.

31. What is the principal use of copper? Of tin? Of zinc?

32. What is the shape of a lead blast furnace?

33. How is zinc produced?

34. How is galvanized iron made?

35. What are alloys? What is the composition of Muntz metal?

36. How is aluminum obtained? How does its electrical conductivity compare with that of copper?

37. What is the advantage of the electrolytic process of refining crude copper?

38. On what properties does the Park's process of desilverizing lead depend?

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